ORGANICS AND ICES IN GALACTIC DUST

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Abstract. Hydrocarbon absorption (3.4 μm) along several different sightlines through the galaxy indicates that the dust carrier lies in the diffuse interstellar medium (DISM). Correlations of the hydrocarbon and silicate absorption features suggest an increased abundance of both in the direction of the galactic center. Dense molecular clouds do not exhibit the same type of 3.4 μm feature as seen in the DISM, which is puzzling in light of dust cycling times. Laboratory organics produced by different processes are compared to the DISM features. The 3.4 μm feature has now been detected in other galaxies, which suggests that the widespread distribution of organic material in our own galaxy may be common to other galaxies as well.

1. Introduction

Near infrared observation of interstellar sightlines in the galaxy have revealed the presence of ices in dense molecular clouds and relatively complex hydrocarbons in the diffuse interstellar medium. The evolution of dust from various birthsites (including the circumstellar environments of stars, supernovae outflows, and dense molecular clouds) is of considerable importance to the overall understanding of the physical processes which dominate the interstellar medium in our galaxy. Advances in near infrared (IR) observational capabilities over the past few years have allowed detailed studies to be made of the distribution and composition of interstellar dust. IR spectroscopy of diffuse interstellar dust has revealed the widespread distribution of absorption features (near 3.4μm) which have been attributed to saturated aliphatic (chain-like) hydrocarbons (Sandford *et al.*,1991; Pendleton *et al.*1994). The recent detection of these bands in other galaxies (Bridger *et al.*,1993; Wright *et al.*this volume) and the remarkable similarity of the

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subfeatures to those in our own galaxy suggest the organic moieties responsible for the 3.4μm absorption bands are widespread in other galaxies as well as our own. Laboratory organics produced by a variety of energetic processes exhibit absorption in the 3.4μm region which is, in general, similar to that observed in the diffuse interstellar medium (ISM). Astrophysically relevant ice mixtures, exposed to ultraviolet radiation, show a very good match to the 3.4μm observations (Greenberg *et al.*1995), although other processes such as the ion bombardment of methane (Strazzulla & Johnson 1991) and the plasma discharge production of hydrogenated amorphous carbons (HACs) (Duley 1994; Jones *et al.*1991) also provide good matches to the DISM (Pendleton et al 1994). In order to discriminate between the relevant processes responsible for the production of the DISM organics, observational studies of the 5-9 μm region are required. The laboratory organics must be able to match the observations at the longer wavelengths as well as in the 3.4 μm region.The 5-9μm spectral region cannot be observed from the ground, but can be observed by the Infrared Space Observatory (ISO). Although there are no ISO observations scheduled to observe the diffuse ISM of our own galaxy in the 5-9μm region, ISO observations are scheduled for a small number of galaxies where the 3.4μm absorption feature has been detected. This paper will briefly discuss the relationship between the observed C-H stretching band (3.4μm) and the observed Si-O stretching band (9.7μm), in which the abundance of each appears to increase in the direction of the galactic center, and problems with a current theory of the cycling of dust between the dense and diffuse clouds are discussed.

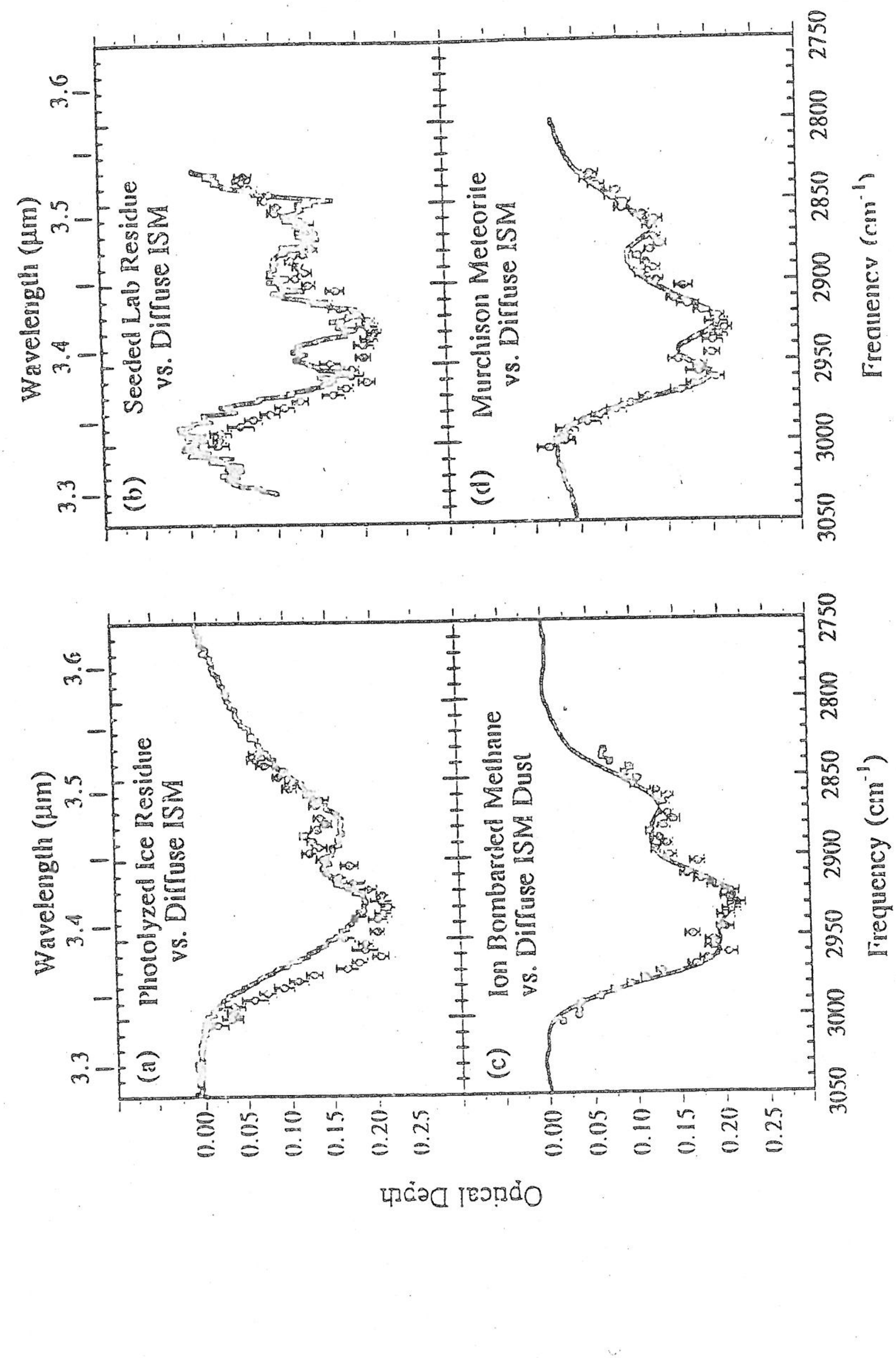
2. Hydrocarbons in the Diffuse Interstellar Medium

Observations of dust in the diffuse interstellar medium have revealed a series of absorption bands near 3.4 μm (Adamson, Whittet, & Duley 1990; Sandford *et al.*1991).The positions of the 3.38μm (2955 cm^{-1}) and 3 .42 μm (2925 cm^{-1}) subfeatures are characteristic of the symmetric C-H stretching frequencies of -CH_3 (methyl) and -CH_2- (methylene) groups in saturated aliphatic hydrocarbons and the band at 3.48 μm (2870 cm^{-1}) is characteristic of the asymmetric C-H stretching vibrations of these same functional groups when perturbed by other chemical groups. The carbonaceous material in the diffuse ISM has an average -CH_2-/-CH_3 ratio of 2.0 - 2.5 and likely contains moderate length aliphatic chains, such as -CH_2-CH_2-CH_3 associated with chemical groups like -OH, -CN, and aromatics. These features have been seen along a dozen different sightlines towards different types of objects in our galaxy. At least 2.5% of the cosmic carbon in the local interstellar medium and 4% toward the Galactic Center is tied up in the carrier of the 3.4 μm band.

Several materials have been suggested as candidate carriers of interstellar carbon. These include: (i) organic grain mantles formed by irradiation of ices (ii) hydrogenated amorphous carbons (HACs) having various degrees of hydrogenation, (iii) Quenched Carbonaceous composite (QCC), a material produced by quenching the plasma of methane gas and (iv) ion bombardment of gas and ices. Comparison of the diffuse interstellar C-H band profiles with the spectra of laboratory samples of candidate analog materials all show general similarities to the interstellar C-H stretching feature. Although the production of the organic residue by UV photolysis of interstellar ice mixtures is the more satisfying pathway, since it closely mimics the processing that should occur in molecular clouds, it may be the case that the material responsible for the 3.4 μm feature is so thoroughly processed that it has lost its "cosmo-chemical memory", and we will never be able to unravel the processing that such material experienced. In that case, we must not ignore the other materials (such as HAC) which are not produced in such a straightforward astrophysical method, but which nonetheless produce a material which appears to be a relatively certain component of the ISM. HAC is a continuum of materials whose properties can be altered by processing in interstellar space through chemical exposure as well as radiation. There are clearly multiple pathways by which the interstellar HAC observed in the diffuse ISM can be produced.

3. Dust Evolution in Dense Molecular Clouds

In the quiescent regions of a molecular cloud, gas phase species collide with the dust particles and stick to them due to the low temperature of the dust. These species include many atomic and molecular radicals. Reactions among these accreted species will form a mixture of simple molecules (d'Hendecourt, Allamandola, & Greenberg (1985)). Further evolution of the grain mantle occurs as it is processed by ultraviolet radiation and/or cosmic rays which penetrate the cloud. Ultraviolet radiation from embedded young stars will also contribute to the grain mantle photolysis and evolution. Such processing produces molecular subgroups and complex molecules which cannot be produced by accretion of reactive species alone (Allamandola, Sandford, & Valero, 1988). After the stellar system has been produced, the cloud remnants are disbursed into the diffuse medium where the volatile components are vaporized and the complex component probably remains on the grains. In this scenario, a new molecular cloud will form from swept up interstellar dust that will include some of this older, first generation material. The relatively short cycling time between dense and diffuse clouds, suggests that the refractory, organic component of the interstellar medium should be seen in both dense and diffuse cloud regions. However, the rel-


Wavelength (μm)
3.3
3.4
3.5
3.6
(a) Photolyzed Ice Residue vs. Diffuse ISM
(b) Seeded Lab Residue vs. Diffuse ISM
(c) Ion Bombarded Methane vs. Diffuse ISM Dust
(d) Murchison Meteorite vs. Diffuse ISM
Optical Depth
0.00
0.05
0.10
0.15
0.20
0.25
Frequency (cm^{-1})
3050
3000
2950
2900
2850
2800
2750

atively complex aliphatic (CH_2 and CH_3 chains) hydrocarbons seen along several sightlines through diffuse cloud dust are notably absent in the spectra of dust embedded dense molecular cloud objects (Brooke *et al.*, 1996).

The spectral signature of 3.4μm wing of the 3.08μm water ice feature seen through dust in the Taurus dark cloud (Smith, Sellgren, and Brooke, 1993) and the 3.47 μm absorption band observed in dense molecular cloud spectra (Allamandola *et al.*1992; Brooke *et al.*1996) are in sharp contrast with that of the diffuse interstellar medium. In comparison, the diffuse dust features straddle the 3.47μm dense cloud feature, and show substructure which is not seen in the 3.4 μm wing of the water ice spectra in the Taurus sources. These differences indicate that there are two very different and independent solid hydrocarbon interstellar dust components. The absence of CH_2 and CH_3 bands in the spectra of embedded protostars may imply that diffuse medium C-rich materials do not get incorporated into dense clouds. It may also imply that the amount of organic refractory material produced in the dense clouds is only a minor contributor to that observed in the diffuse ISM. A possible avenue for study of the process responsible for the production of the DISM organics is to observe the predicted intermediate or resultant steps along the way of the process of interest. For instance, Bernstein *et al.*, 1995 have shown that as much as 60% of the organic residue produced through the UV photolysis of ices is attributable to the Hexamethylenetetramine (HMT), $C_6H_{12}N_4$, molecule. Upon further irradiation, the so called X-CN (4.62 μm) feature appears. The X-CN absorption feature has been detected towards a small number of sources and is always seen through dense cloud dust. A recent study by Tegler *et al.*(1995) reports a preliminary discovery that the X-CN feature is not detected in the dust towards background stars but is apparent in the embedded star spectra when observing stars through similar amounts of dust obscurration in the Taurus cloud. This result could have a strong impact on constraints placed upon the production requirements and/or the extent to which dust grain mixing typically occurs throughout a molecular cloud. Another comparative study that would be useful is a study of the presence and detailed shape of the X-CN band in different molecular clouds. Variations from cloud to cloud might well depend upon such factors as the rate of star formation, the mass of the stars forming, etc.

3.1. HYDROCARBONS AND SILICATES IN OUR GALAXY

The A_v/tau ratio for the 3.4 μm feature is lower toward the Galactic Center than toward sources in the local solar neighborhood (Sandford, Pendleton, & Allamandola, 1995). A similar trend has been observed previously for silicates in the diffuse medium (Roche & Aitken 1985), suggesting that (i)

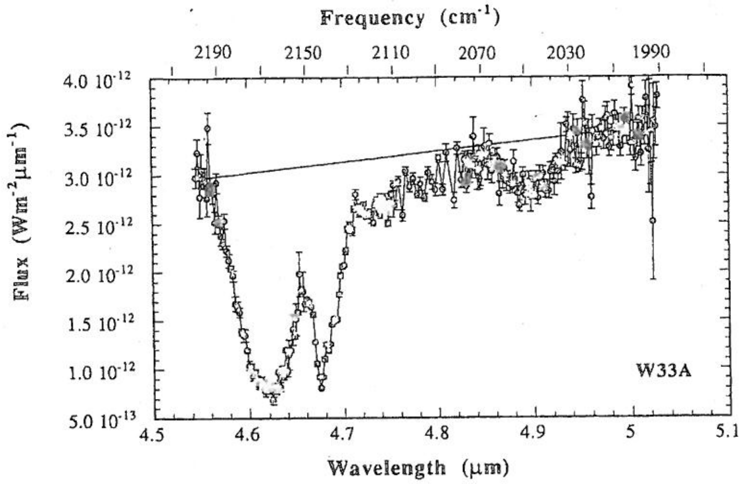


Figure 2. XCN, CO, and OCS in W33A (Pendleton, Tielens, & Tokunaga, 1996)

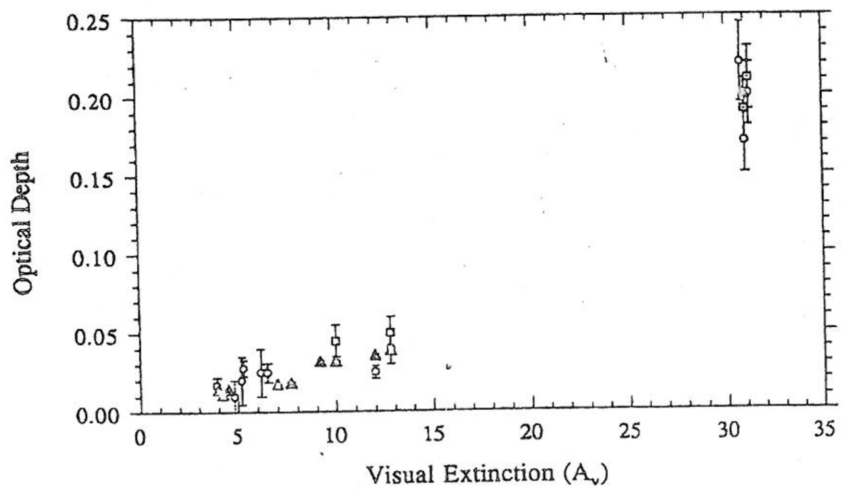


Figure 3. A_v versus optical depth of the C-H (open points) and Si- O bands (Sandford, Pendleton, & Allamandola, 1995)

the silicate and carbonaceous materials in the DISM may be physically correlated and (ii) there is either dust compositional variation in the galaxy or galactic variation in the grain population density distribution. The similar behavior of the C-H and Si-O stretching bands illustrates the possiblilty that these two components may be coupled, perhaps in the form of silicate-core, organic-mantled grains, as proposed by J. M. Greenberg years ago. Comparisons of the 3.4 μm and 9.7μm absorption bands in other galaxies will provide an additional view of this complex situation.

4. Summary

Through high resolution, high signal-to-noise observations we have learned that the interstellar medium in our galaxy contains an organic component which is widely distributed throughout the diffuse medium. This compo-

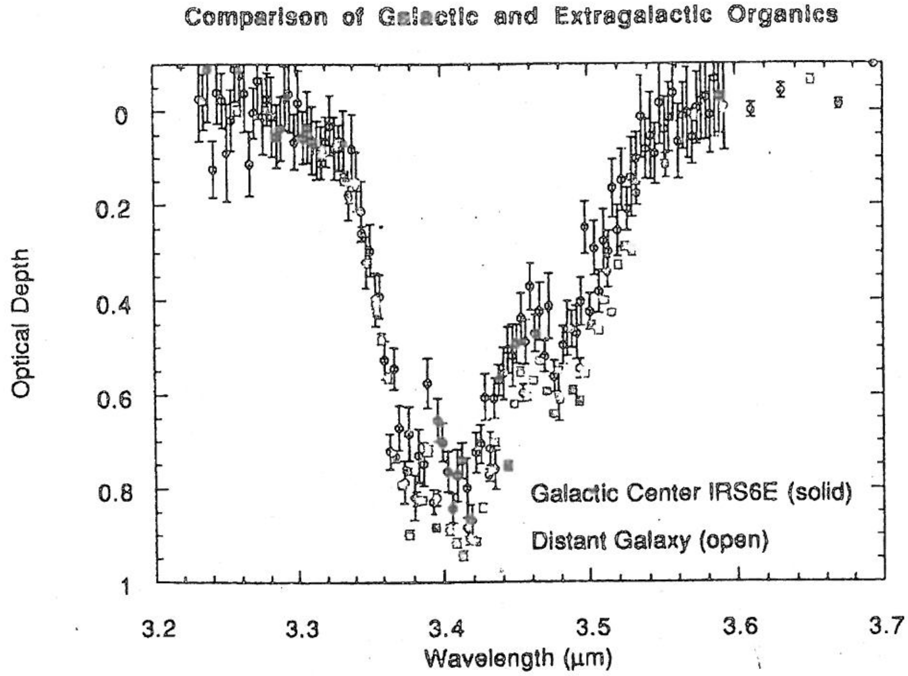


Figure 4. Comparison of the 3.4μm feature in the embedded Seyfert Galaxy IRAS 08572+3915 and the Galactic Center source GC IRS6E

nent is not seen in dense molecular clouds, even though it is predicted to be there if dust cycles between the diffuse and dense clouds with the efficiency that has been suggested. Laboratory comparisons of organic material produced through a variety of methods have revealed that more than one end product can provide a good detailed match to the observed diffuse ISM. The residue produced through UV photolysis has the advantage of replicating an astrophysically relevant situation, but if the organic residue that we observe has lost its "cosmochemical memory", then well fitting organics produced by alternative means (such as HACs) should be given equal consideration as the possible carrier for all or some of the 3.4μm feature. In order to discriminate between the relevant processes, which in turn might reveal where the organics are produced, observations in the 5-9μm region are required. Another direction for studies of the physical processes will be to look closely at the intermediate or resultant steps which are predicted as a result of the specific process to be investigated. In the case of UV photolysis, for instance, the photolyzed organic residue composition consists of 60% HMT. The UV photolysis of HMT produces an X-CN feature. We can observe the X-CN feature in dense clouds, comparing the distribution of the carrier throughout the cloud and comparing cloud-to-cloud variations to reveal the extent of the photolytic process on the organic refractory residue. The discovery of the 3.4μm absorption feature in other galaxies is a result of the vast improvement in instrumentation that has become available just recently. The surprising discovery of a much stronger 3.4μm feature in a distant galaxy than the strongest measurement observed in our own galaxy has opened new vistas that show great promise. Now we may be able to study interstellar features in other galaxies that are obscured by telluric lines in the Earth's atmosphere (when observing galactic objects) because the features of interest will be redshifted corresponding to the distance of the galaxy. The widespread distribution of the organic component throughout our galaxy and possibly other galaxies underlines the possibility that the basic building blocks of life are available for incorporation into planetary systems forming throughout the universe.

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